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OPTIMIZATION OF FEED POSITION WITHIN TRIAD OF SYMMETRICAL V-SLOTS LOADED RECTANGULAR MICROSTRIP PATCH ANTENNA

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***Abstract*– The probe fed symmetrical V-slots loaded rectangular microstrip patch antenna is proposed. The purpose of this paper is to examine the effect of rotation of feed point within the triad of symmetrical V-slots. The antenna is found suitable to deal with the S (2-4 GHz), C (4-8 GHz), X (8-12 GHz) and Ku (12-18 GHz) bands applications simultaneously. These applications are Bluetooth (2.4 GHz), WiMAX (2.5GHz), long distance radio communication (5-7 GHz), terrestrial broadband, radar etc. The performance is analyzed on the basis of parameters return loss, VSWR, gain and radiation pattern.**

***Keywords* – patch antenna, symmetrical V-slots, probe feed, gain, multiband applications.**

I. INTRODUCTION

The microstrip patch antenna belongs to the category of printed antennas. These are used mostly because of good radiation control, ease of integration with active devices and low cost of fabrication. Basically, it consists of four elements that are patch, substrate, ground plane and the feeding part. The performance of patch antenna depends upon the properties of each element. The metallic patch is normally made up of thin copper foil plated with the corrosion resistive metal such as gold, nickel or tin [1-2]. The patch acts as an infinite sheet of charges with uniform surface charge density (ρ_s) in Coulomb/m^2, which is responsible for the radiation effect. Most commonly the Patch antennas are fabricated on thick substrates. The substrate should have low dielectric constant ($\epsilon_r \leq 10$) to obtain superior radiation efficiency and larger impedance bandwidth [3]. The way a microstrip patch antenna is excited determines the direction of the radiated fields, the feasible impedance bandwidth, the ease of manufacturing of antenna and the efficiency of overall antenna [4-8]. There are four basic methods to excite or feed a patch antenna, these are edge-fed, coaxial probe-fed, aperture coupled and proximity coupled. Among these, the edge-fed and probe-fed lies in the category of contact mode of feeding, whereas aperture and proximity coupled are the types of non-contact feeding method [9]. According to today's necessity for wireless devices, the multi-frequency integrated antennas are the most desired option to deal with multiple applications simultaneously [10-11]. These applications are Bluetooth, WLAN, WiMAX, GPS (S-band) and satellite communication, radar (C, X-bands) and terrestrial broadband, space communication (X, Ku-bands).

In this research work, we have designed an antenna using symmetrical V-slots forming a triad on the antenna aperture. We have used coaxial probe fed technique to excite the antenna. The optimization of feed point is done to make the designed antenna response as good as possible. Our objective is to study the effect of variation of feed position vector within the differed triad of symmetrical V-slots on the resonant bands, return loss impedance, gain, radiation pattern and VSWR. As we are rotating the feed position anti-clockwise within the slots, we are obtaining the maximum gain of 12.78 dB.

II. THEORY AND ANALYSIS

The structure for guiding a wave is chosen by: (a) the desired operating frequency bands, (b) the amount of power to be transferred and (c) the amount of transmission losses that can be tolerated. We are using coaxial probe feeding to excite the designed antenna. This method of feeding is useful for frequencies below 3GHz, above that the loss effect increases because of heating of coaxial conductors and of the dielectric between the conductors. The amount of EM field generated is totally dependent on how we are feeding the antenna [12]. The antenna uses voltage and current from the transmission line (coaxial feed pin in this case) to launch the EM wave energy into the medium (substrate). Two-conductor transmission line supports a transverse electromagnetic (TEM) wave, in which the electric and magnetic fields on the line are perpendicular to each other and transverse to the radial direction of wave propagation (z-axis). According to the Ampere's law, the H field encircles the current carrying conductor as shown in figure 1. The Poynting vector ($P = E \times H$) is pointing along the transmission line.

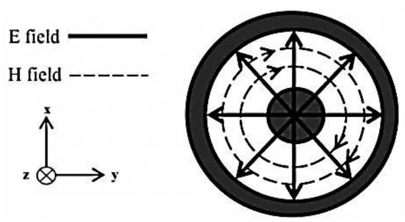

Fig.1. **E** and **H** fields on the coaxial line

As the electric fields can exist in the free space, these can also exist in material media. The substrate is a dielectric medium in which the charges are not able to move freely, but are bound by finite forces. There may a displacement of charges when an external applied force. This shape and dimension of the waveguide decides the transmission mode of wave. The patch drawn in xy-plane is shown in the fig. 2.

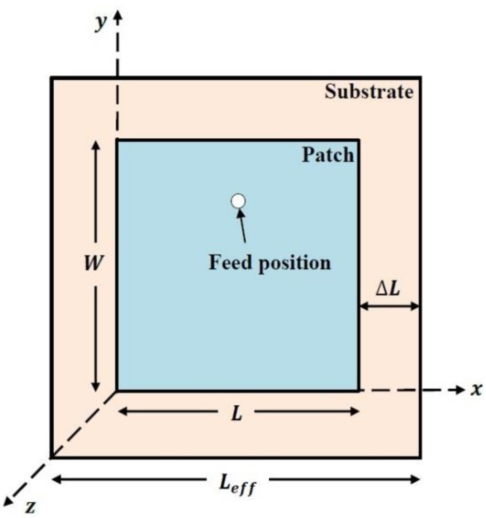

Fig.2. 2D view of probe fed microstrip patch antenna

The radiation effect of patch antenna is due to *fringing field phenomenon*. It is assumed that the waveguide is filled with the source free ($\rho_v = 0, J = 0$) lossless dielectric material ($\sigma \cong 0$) and also that its walls are perfectly conducting ($\sigma \cong \infty$). For lossless medium, Maxwell's equations in phasor form are given as 1(a) and (b)

$$\nabla^2 E_s + k^2 E_s = 0 \qquad (1(a))$$

$$\nabla^2 H_s + k^2 H_s = 0 \qquad (1(b))$$

Where,

$$k = \omega\sqrt{\mu\epsilon} \qquad (1(c))$$

And $E_s = (E_x, E_y, E_z),\ H_s = (H_x, H_y, H_z)$

The time factor with which the fields are varying is assumed as $e^{i\omega t}$. We have used the Maxwell's equation to solve for E and H fields. The direction of propagating wave is assumed to be in positive z direction with propagation constant γ from 2(a) and (b).

$$\nabla \times E_s = -j\omega\mu H_s \qquad (2(a))$$

$$\nabla \times H_s = -j\omega\epsilon E_s \qquad (2(b))$$

We can calculate the x and y component of electric and magnetic field using only their z component using 3(a, b, c, d).

$$E_x = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial x} - \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} \qquad (3(a))$$

$$E_y = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial y} + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x} \qquad (3(b))$$

$$H_x = -\frac{\gamma}{h^2}\frac{\partial H_z}{\partial x} + \frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial y} \qquad (3(c))$$

$$E_y = -\frac{\gamma}{h^2}\frac{\partial H_z}{\partial y} - \frac{j\omega\epsilon}{h^2}\frac{\partial E_z}{\partial x} \qquad (3(d))$$

Where, $h^2 = {k_x}^2 + {k_y}^2$.

These components of E and H fields for TE ($E_z = 0, H_z \neq 0$) and TM ($H_z = 0, E_z \neq 0$) mode are shown in fig. 3.

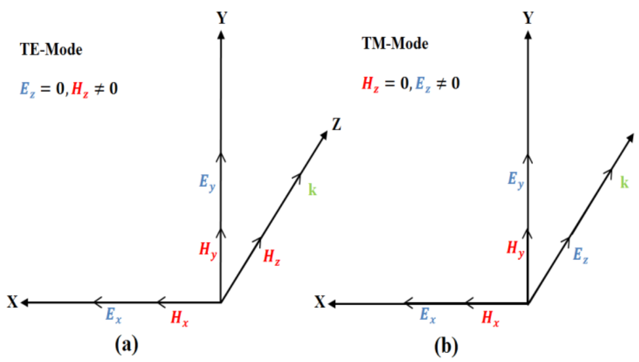

Fig.3. Components of EM fields in a rectangular waveguide: (a) TE mode $E_z = 0$, (b) TM mode $H_z = 0$

For TM mode, ($H_z = 0$), Using boundary conditions for (4).

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$$E_z = E_o \sin k_x x \,.\, \sin k_y y \,.\, e^{-\gamma z} \quad (4)$$

By solving we get,

$$\sin k_x L = 0\,, \qquad \sin k_y W = 0$$

$$k_x L = m\pi\,, \qquad m = 0,1,2,3 \ldots$$

$$k_y W = n\pi\,, \qquad n = 0,1,2,3 \ldots$$

$$k_x = \frac{m\pi}{L}\,, \qquad k_y = \frac{n\pi}{W} \quad (5)$$

Putting the values from (5) to (4), E_z is calculated as

$$E_z = E_o \sin(\frac{m\pi}{L} x) \,.\, \sin(\frac{n\pi}{W} y) .\, e^{-\gamma z} \quad (6)$$

And value of k as a function of dimensions is given by (7).

$$k^2 = \omega^2 \mu \epsilon = \left[\frac{m\pi}{L}\right]^2 + \left[\frac{n\pi}{W}\right]^2 \quad (7)$$

Using (7) and 1(c), putting $\omega = 2\pi f_o$ where f_o is the resonant frequency, we can solve (7) for it as

$$f_o = \frac{1}{2\sqrt{\mu\epsilon}} \sqrt{\left[\frac{m}{L}\right]^2 + \left[\frac{n}{W}\right]^2} \quad (8)$$

The point to note here is that the ($E_z = H_z = 0$) TEM mode is not supported by rectangular waveguide. For TE and TM modes, (m, n) may be (0, 1) or (1, 0) but not (0, 0). Both m and n can't be zero at the same time because this mode vanish the field components (using (6)). The mode can be TE_{10} or TE_{01} depending upon the values of L and W of guide. The TE_{10} mode is the lowest mode, also called as dominant mode, is of practical significance. The resonant frequency for TE_{10} mode is obtained from (8) as (m = 1, n = 0)

$$(f_o)_{10} = \frac{1}{2L\sqrt{\mu\epsilon}} \quad (9)$$

We can evaluate E and H field using explained theory. The dimensions are calculated using standard equations of rectangular microstrip patch antenna before modeling the antenna.

III. DESIGN CONSIDERATIONS

The designed antenna is modeled using the ANSYS HFSS software for simulating 3-D, full-wave, electromagnetic fields. The structural and dimensional view of designed antenna is presented in figure 4. The dielectric material used for substrate is Roger's duroid RT-5880 having relative permittivity $\epsilon_r = 2.2$ and permeability $\mu = 1.0$. Whereas, the material used for patch is copper whose relative permittivity $\epsilon_r = 1$ and permeability $\mu_r = 0.991$. The coaxial probe feeding is used to excite the designed antenna because it is easy to maintain impedance matching using this feeding technique. The symmetrical V-shaped slots are used to form triad and are etched from the antenna aperture. The angle between each triad is kept approximately 120°. These slots under the influence of electromagnetic waves, radiates like an ordinary dipole antenna. Creating cavity on the patch surface causes the reduction of effective area of the conducting patch. This reduction causes the increase of surface current charge density, which in result affects the return loss. The diameter of probe is 0.7mm. The designed antenna is enclosed within a radiation box containing air or vacuum inside it. The values of all the other dimensional parameters of designed antenna are given in table 1.

TABLE I. Design specifications

S. no.	Parameters	Value (in mm)
1.	Length of substrate (L)	80
2.	Width of substrate (W)	70
3.	Height of substrate (h)	3.2
4.	Length of patch (L_P)	40
5.	Width of patch (W_P)	40
6.	Length of slot (L_S)	5
7.	Width of slot (W_S)	1

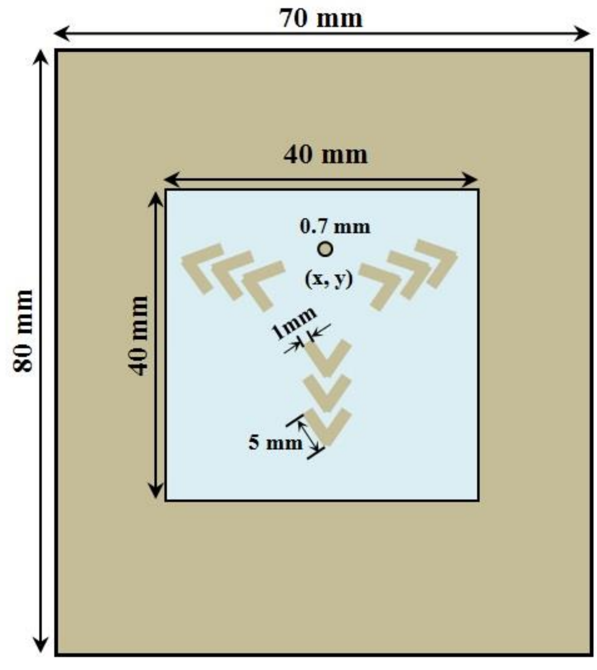

Fig.4. Dimensional view of designed antenna

IV. SIMULATION RESULTS AND DISCUSSIONS

The performance parameters show significant variation with respect to the change in feed coordinates within the triad of symmetrical V-slots. The simulated parameters at three different coordinates are stated in the table 2. The results show that as we are varying the feed point anti-clockwise there is a change in the resonant frequency bands, return loss, bandwidth and gain of the designed antenna. We have varied three feed position (-10, 0), (4, -8) and (2, -1) (shown in fig.5) in such a

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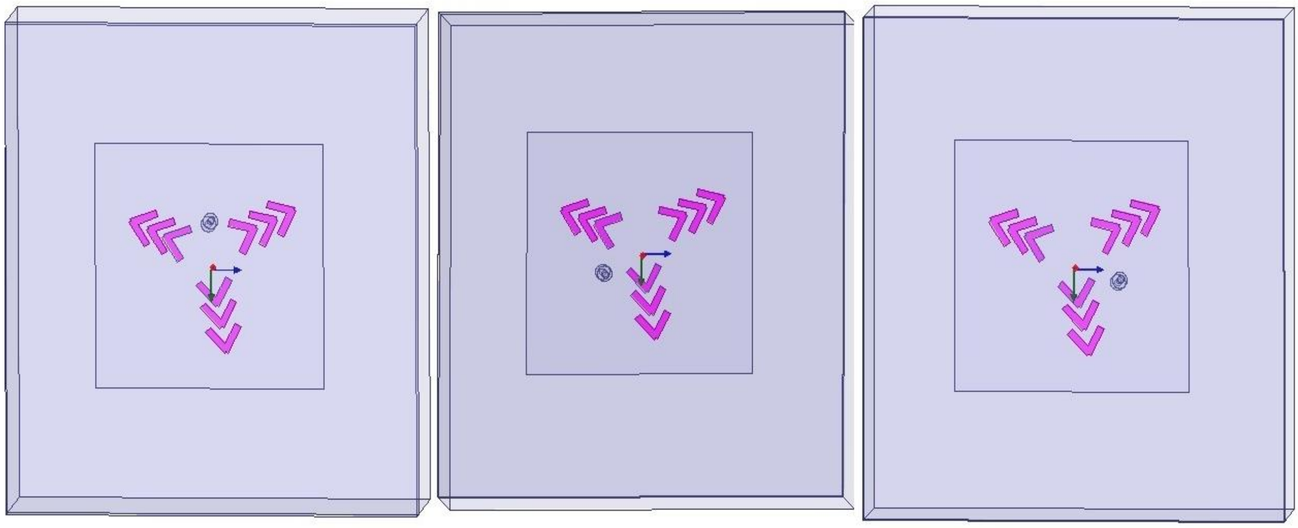
way that the performance characteristics show significant change in their parametric values and simulated results.



(a) feed position (-10,0) **(b) feed position (4,-8)** **(c) feed position (2, 10)**

Fig.5. Top view of proposed antenna with varied feed positions

Table -1 Parametric specification of performance characteristics

Feed Position (X, Y)	Resonant Frequencies (GHz)	Return Losses (dB)	Bandwidth (%)	Gain (dB)
(-10, 0)	**5.40**	**-16.08**	**1.85**	**9.49**
	7.30	**-14.63**	**6.16**	**8.77**
	8.40	**-12.27**	**2.97**	**10.05**
	9.80	**-15.19**	**6.63**	**11.01**
(4, -8)	**5.26**	**-11.79**	**1.95**	**8.48**
	6.73	**-14.32**	**0.71**	**9.20**
	7.93	**-25.25**	**1.89**	**9.87**
	9.26	**-19.96**	**8.60**	**8.83**
	12.06	**-34.07**	**12.16**	**8.14**
	14.86	**-19.44**	**3.38**	**12.28**
(2, -10)	**5.40**	**-12.26**	**1.74**	**9.43**
	7.40	**-12.32**	**7.20**	**8.47**
	8.46	**-16.41**	**3.17**	**9.69**
	9.40	**-17.17**	**5.67**	**8.80**
	10.86	**-15.20**	**2.45**	**10.47**
	11.53	**-29.00**	**3.47**	**8.67**
	12.33	**-31.17**	**3.24**	**9.96**
	14.60	**-20.55**	**7.31**	**12.78**

For feed position (-10, 0), we are obtaining four resonant bands (5.40, 7.30, 8.40 and 9.80 GHz) (shown in fig. 6 (a)) and the maximum gain comes out to be 11.01 dB at 9.80 GHz. For feed coordinates (4, -8), six significant resonant bands (5.26, 6.73, 7.93, 9.26, 12.06 and 14.86 GHz) are acquired (shown in fig. 6 (b)) and the maximum gain calculated is 12.28 dB at 14.86 GHz. For feed position (2,-10), eight resonant bands (5.40, 7.40, 8.46. 9.40, 10.86, 11.53, 12.33 and 14.60 GHz) are observed (shown in fig. 6 (c)) and the maximum gain is 12.78 dB at 14.60 GHz. Fig. 7 is representing the radiation patterns of the proposed antenna at different feed positions. At each feed position, the antenna is giving unidirectional directive gain. The E and H fields can be calculated using the radiation pattern. According to cylindrical coordinates (r, θ, φ), the $\varphi = 0^{\circ}$ gives the value of electric field E and $\varphi = 90^{\circ}$ gives the value for magnetic field H. Depending upon the value of E and H, we can determine the value of transmission mode in which the electromagnetic wave is traveling. The value of VSWR observed is between 0.5 and 2.5 (shown in fig. 8) which approximately lies in the standard range for VSWR with minimum reflections of EM waves that is $1 \leq VSWR \leq 2$. Figure 9 is showing the 3-D polar plot of gain for the resonant frequency of 2.25 GHz at three feed position. As we are rotating the feed position in anti-clockwise direction, we are achieving the maximum gain of 12.78 dB at 14.60 GHz when the coordinates of feed position are (2, -10).

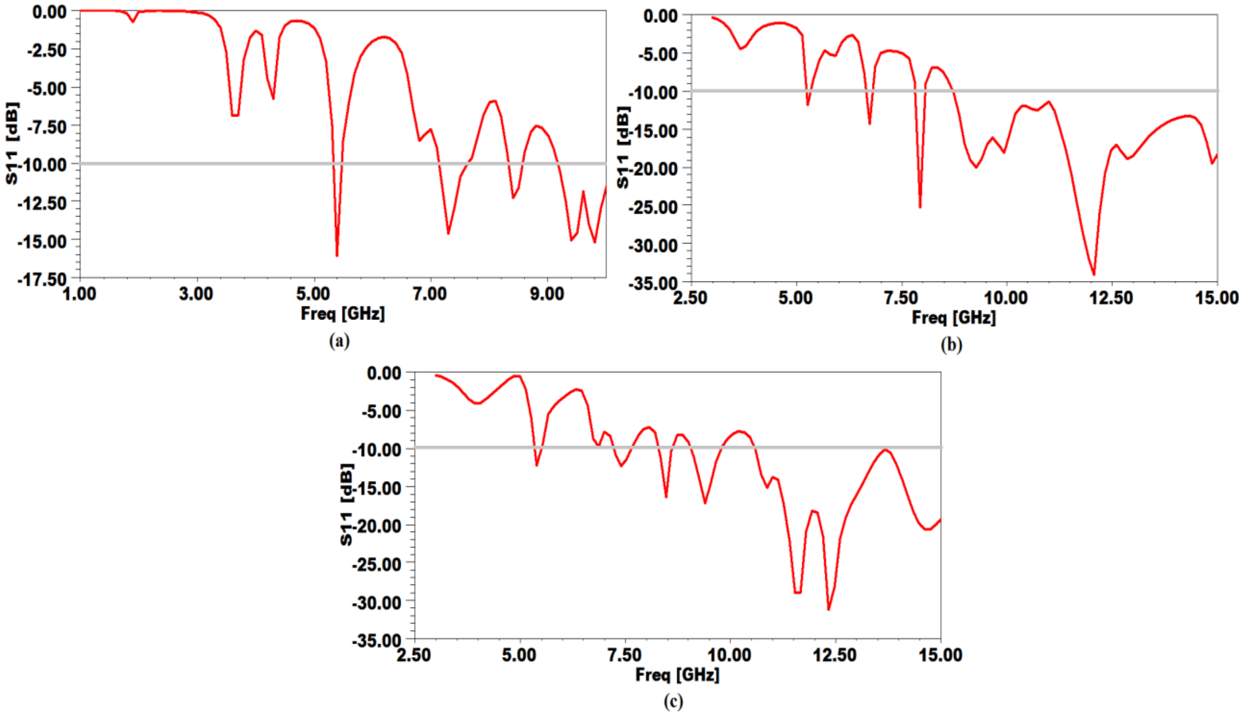


Fig.6. Return loss vs. frequency plot of proposed antenna with feed position (a) (-10, 0), (b) (4, -8) and (c) (2, -10)

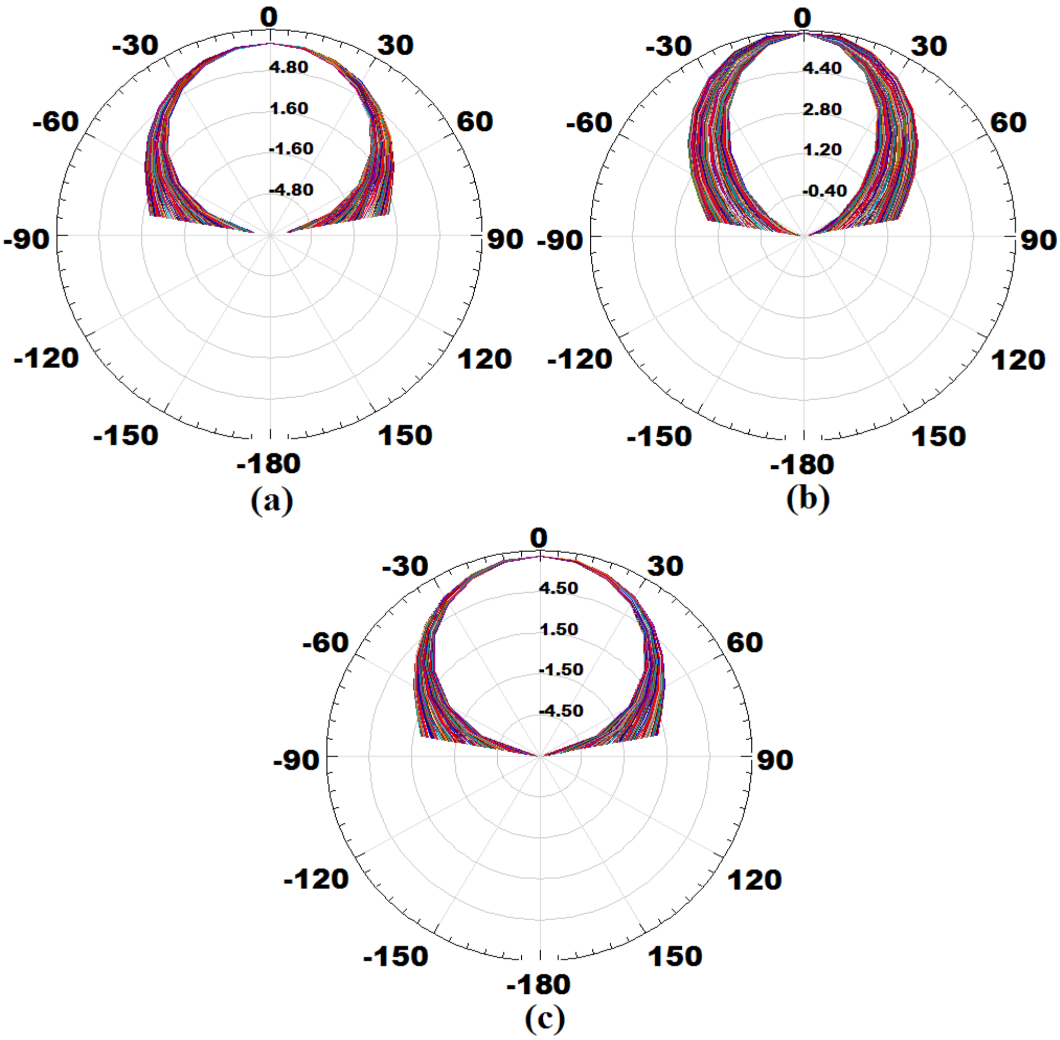


Fig.7. Far field radiation pattern of proposed antenna with feed position (a) (-10, 0), (b) (4, -8) and (c) (2, -10)

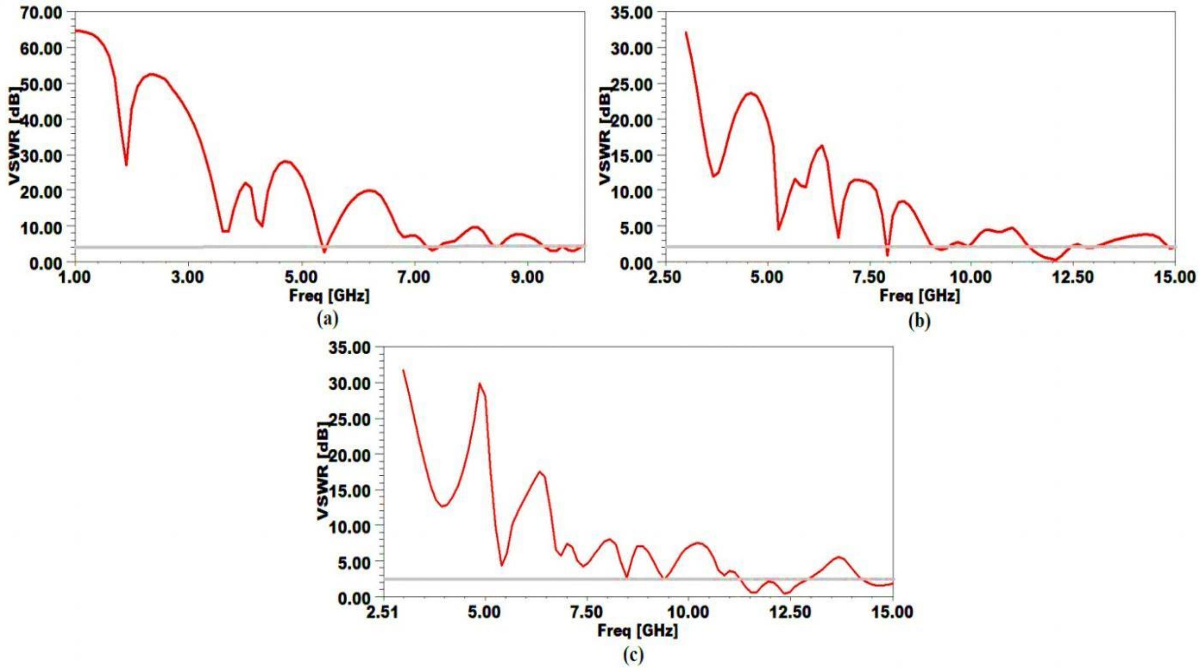


Fig.8. VSWR vs. Frequency plot at feed position (a) (-10, 0), (b) (4, -8) and (c) (2, -10)

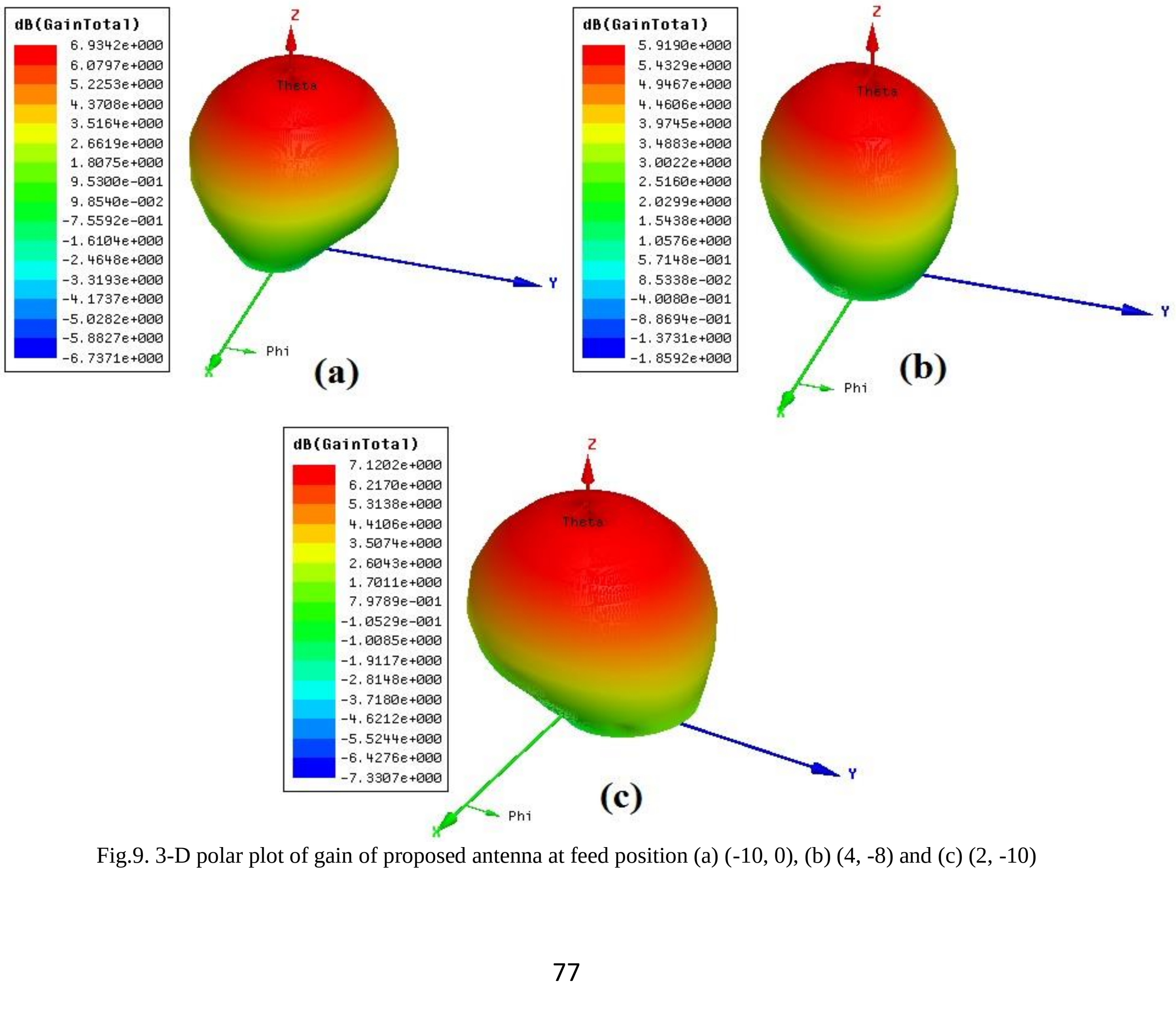


Fig.9. 3-D polar plot of gain of proposed antenna at feed position (a) (-10, 0), (b) (4, -8) and (c) (2, -10)

V. CONCLUSION

The proposed work is done for viewing the effect of variation of probe feed position on the performance characteristics of the antenna designed for 2.25 GHz. The slot effect and the change in the position of probe significantly affect the transmission modes of the electromagnetic wave and thus the resonant frequency bands. The coaxial probe feed is used for the present work because it is easy to change position of probe and to satisfy the impedance matching condition. The simulations show that the anti-clockwise rotation of feed position within the triad of symmetrical V-slots gives more convincing results at feed position (2, -10). The maximum gain of 12.78 dB is obtained at the resonant frequency 14.60 GHz. The importance of work done is that the antenna can be used to deal with different applications of microwave frequency region. The future scope of the work is that we can try this method for different shape of slots and also for different types of feeding methods for enhancement of antenna performance.

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